ISYE 320 Final Report

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1. Introduction and Problem Motivation

1.1 The System

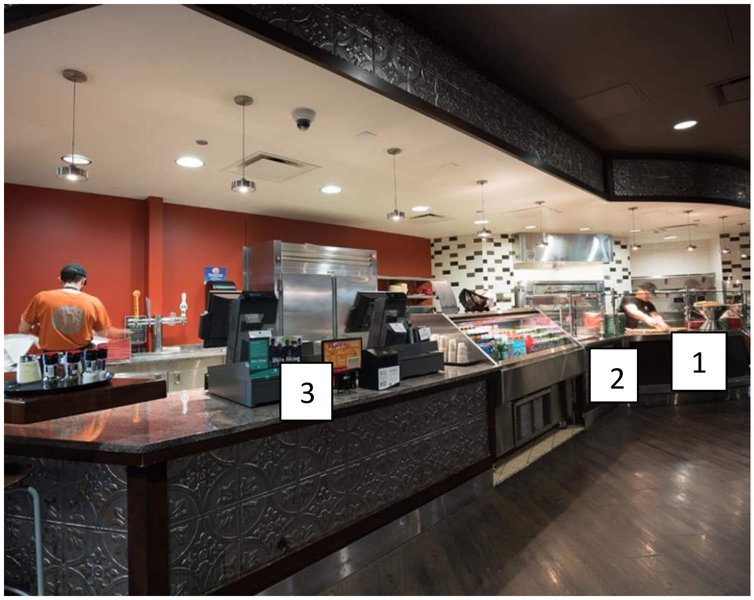

Figure 1: Image of System with Labeled Stations

South Cantina is a university owned restaurant in the Union South building on the University of Wisconsin-Madison campus. South Cantina is a counter style restaurant with three primary sequential stations that process food orders. The customer follows the food being prepared from station to station. The three stations include a protein/base station (1), a toppings station (2), and a register station (3) as seen in *Figure 1*. A fourth station is occasionally added between the toppings and register station, where an additional employee assists in the closing of a burrito bowl or the wrapping of a tortilla. Each station is staffed by a single employee. This process is fed through the base station by a line of customers waiting in a queue. The team studied the system at lunchtime from 11 am to 2 pm on 4 separate weekdays. This time was chosen because it is during the peak lunch rush, when students are frequently passing through Union South. Modeling the system during peak demand allows for more effective analysis and suggested changes, as improvements are less necessary for times of low demand.

Customers leaving the queue and entering the sequence of processes begin by telling the employee at the base/protein station whether they would like a burrito, a burrito bowl, taco, nachos, or salad. The employee picks up the respective container and fills it with the customer's base selection. This employee then hands the container to their right to the next employee staffing the topping station. During times of high demand, if necessary, WIP is held on counters between employees.

At the topping station, the employee asks the customer what toppings they want. The customer has an option to choose from both standard toppings and premium toppings. With all orders, customers can choose an unlimited number of standard toppings, but premium toppings can be added at an additional cost. The employee will add the selected toppings to the container and either close the container themselves, or hand it to their right to the next employee manning the occasionally utilized closing station. Either the topping station employee or the closing station employee then closes the container with the respective lid or wraps the burrito with foil, which is then handed to the customer.

Once the customer has received their order, they move to the register. The employee at the register station asks the customer if they selected any premium toppings and asks them if they would like a drink with their meal. After calculating the total cost, the employee asks the customer what method they would like to pay with and offers to give the receipt after the payment is approved. The customer can then exit the restaurant.

1.2 Key Performance Indicator

The team will use the maximum queue length as the key performance indicator. Maximum queue length is particularly indicative of South Cantina's performance because a large queue disrupts foot traffic in Union South. During times of peak demand, it is crucial that the queue does not extend into the hallway outside of the restaurant. The queuing area for South Cantina can accommodate roughly eight people without extending into the walkway. Other KPI's, such as time in system, were not used because they were deemed less impactful to South Cantina's success. The team decided that a reduction in South Cantina's already brief time in system, while beneficial, was not the primary goal of the proposed change. A preliminary goal for the average maximum queue length across replications is six entities. This maximum queue length allows for all customers to be contained within the South Cantina queuing area and allows for a buffer of two people before the line disrupts foot traffic in Union South. A secondary goal is for the maximum queue lengths observed across all replications to be below eight people, at which point the line would extend into the walkway.

1.3 Report Summary

In the following sections, this report outlines two approaches to potentially improve the system relative to the KPI of maximum queue length. The following two sections will provide an overview of the current state of the simulation and the baseline KPI values. This will be followed by proposing tactical and strategic changes to improve the system. Both potential changes were analyzed regarding their effectiveness at reducing the KPI. Statistical analyses and cost estimates are made to determine whether either change should be implemented, and a final recommendation is made.

2. The Current State Simulation

The simulation was constructed by measuring how long each process took over four days. Data was collected between 11 am and 2pm during weekdays, as this is the period of peak demand. 50 data points were collected for the base, toppings, and checkout stations, and 102 data points were taken for interarrival times. Data was only taken when the occasional closing station was not present. Therefore, this simulation only models the process when three stations are used.

Interarrival times were taken by recording every customer on a single day across a two-hour timespan to control inconsistent interarrival rates due to period breaks at the university.

The process time distribution for each of the four processes (arrivals, base station, toppings station, and checkout station) were determined by visual analysis of histograms and QQ plots, and a Chi Squared test. The distributions and MLE parameters for the four distributions are shown in *Table 1*.

Table 1: Process Distribution and MLE Parameters

Process	**Distribution (parameters in seconds)**
Interarrivals	Exponential (lambda = 62.5)
Base Station	Normal (mean=29.3, standard deviation = 12)
Toppings Station	Normal (mean=40.2, standard deviation = 15.9)
Register Station	Normal (mean=22.7, variance = 9.31)

The process was modeled by using a create module to introduce entities to the simulation at a rate determined by its exponential maximum likelihood estimation (MLE) parameter. These entities pass through three sequential process modules that progress entities at a rate determined by the parameters of each of their normal distributions. Each process has its own resource, which simulates how one employee is stationed at each process in the real-world system. These process modules are set to seize, delay and release. This allows each entity that enters the process to seize the resource, be delayed by a time determined by the normal distribution, before both the entity and resource are released. Entities finally leave the system through a dispose module. The Arena model of the simulation is shown in *Figure 2*.

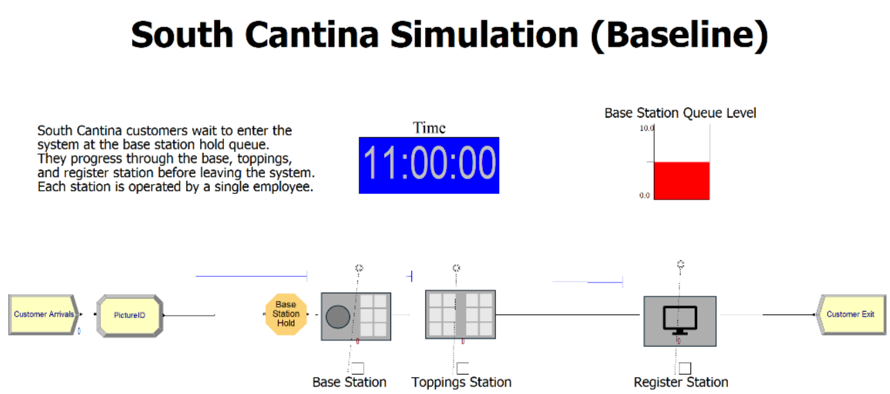

Figure 2: Arena Simulation of South Cantina

Several changes were made from the original model included in the mid-term report. Each replication now still consists of a three-hour day to represent the midday lunch rush which was studied during the data collection; however, the warm-up period has been increased to half an hour. This allows enough time for the simulation to reach a steady state before data is recorded.

A major change is the addition of a hold prior to the base station. This was added to restrict the queue that can form between the toppings station and the base station. The previous version of the simulation allows for an unrestricted queue to form in front of the toppings station. The base station will not begin removing people from its queue until the toppings station queue is empty. To control this, the base station's queue has been replaced with a hold module that only releases entities if the base station is available and the toppings station queue is zero.

The new simulation passes the face validity check, as entities only leave the hold module when the base station has released its entity, and the toppings station does not have a queue. A queue of one person occasionally forms in front of the toppings station, which is expected and is consistent with the real-world system. A small queue of a few people occasionally forms in front of the register station, which is also consistent with the actual system's behavior. There is no limit on the size of this queue, however roughly 6-8 people can wait in the queue between the toppings station and the register comfortably. The simulation rarely allows for that many people to accumulate between those processes, so it was not controlled with a second hold module.

Given the changes to the simulation, the team performed a new statistical validation test. Statistical model validation was performed by comparing the average number of customers in the system with 17 data points collected after the simulation was created and verified. These data points were taken from 12:40 pm to 2:00 pm in intervals of 5 minutes. They are shown below in *Table 2*. Note that this is the same validation data used for the midterm report.

Table 2: Validation Data of Customers in System

Number of customers	Time
7	12:40
5	12:45
4	12:50
5	12:55
3	1:00
3	1:05
1	1:10
4	1:15
5	1:20
3	1:25
1	1:30
2	1:35
1	1:40
1	1:45
0	1:50
0	1:55
1	2:00

A replication-deletion method of creating data points was used to generate data points for the validation. 20 replications (days) of the simulation were run and the average number of entities in the system was averaged across these replications. This average was compared to the average number of customers in the system from the validation data. The test was performed with the following hypotheses:

H_o: The validation and simulation means are equivalent (null hypothesis)
H_1: The validation and simulation means are not equivalent (alternative)

This test is performed to determine whether the difference between these means could be generated by a normal random variable with a mean of zero. This was conducted by performing a t-test with an alpha value of .05 (*Table 3*).

Table 3: Validation t-test Data and Calculated Values

Validation Mean	2.705882353
Simulation Mean	2.526
n	20
Simulation Standard Deviation	0.5891
Test Statistic	-1.365571785
Degrees of Freedom	19
Critical Value	2.09302

The new simulation passes the validation test, as the test statistic's absolute value is less than the critical value from the t distribution table. Given that the simulation passes both the face validity and statistical test, the team is comfortable using this simulation for further experimentation.

3. Baseline Simulation

The team analyzed recent enrollment growth at the nearby University of Wisconsin-Madison to determine whether South Cantina can expect an increase or decrease in demand over the coming years. The university does not provide growth projections; however, they do provide enrollment numbers by year and department. South Cantina is located near the UW-Madison's engineering campus, so enrollment data over the past ten years for the engineering school was studied. This data is shown in *Figure 3*; note that the grey bar represents undergraduate students, and the red represents graduate students.

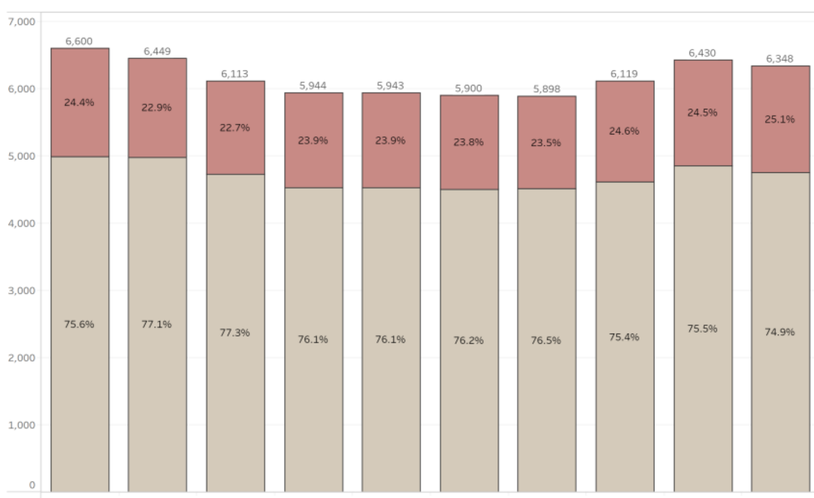

Figure 3: UW-Madison Engineering Enrollment by Year [1]

The lack of a significant trend does not allow the team to create our own projections for an increase or decrease in students. Therefore, no increase or decrease in demand will be modeled in the baseline simulation. This decision was also affected by the intention that any proposed changes will be effective in the short term, requiring at most a year to implement. Therefore, no changes have been made to arrival rates or process cycle time distributions to account for any projected external changes.

The current system's performance relative to the KPI's across 20 replications is summarized in *Table 4*.

Table 4: Simulated Maximum Base Station Queue Length Statistics Relative to KPI Goals

Maximum Base Station Queue Length Statisic	Simulated Value	KPI Goal
Mean	6.2	≤6
Standard Deviation	1.704483252	N/A
Maximum	10	≤8

The simulated values for maximum base station queue length are larger than the goals for this KPI. *Table 5* shows a 95% confidence interval for the KPI mean value.

Table 5: 95% Confidence Interval of the Mean Maximum Queue Length KPI

KPI Mean	6.2
KPI Standard Deviation	1.704483252
n	20
Alpha	0.05
t(19, .025)	2.09302
CI Upper Bound	6.997721172
CI Lower Bound	5.402278828

The confidence interval of the mean maximum queue length partially overlaps with the goal of less than 6. This demonstrates that there is a smaller than 50% chance that the KPI mean lies within the goal set by the team. Therefore, the system will require improvements to ensure with greater likelihood that the mean value of the KPI lies within the satisfactory region. This is also supported by the maximum simulated queue value (10) lying above the set goal of eight. The proposed system improvements aim to reduce both values to within their satisfactory ranges.

4. Proposed System: Tactical Improvement

Currently the order and payment process require every customer to interact with a separate employee at each station, which leads to the formation of a queue before the first station. This queue becomes especially long during peak hours resulting in queue spillovers outside the restaurant and into the Union South hallway. To combat this, we propose South Cantina adopts a conveyer system where the employees follow the customer through all stations and return to the base station when they are finished. Implementing this conveyer system will allow us to reduce the initial queue length by balancing employee utilizations and eliminating the time taken to hand over orders between employees.

While modeling our simulation, we set up our process modules like the baseline with one key difference. In the baseline simulation, all of processes used a different resource with a capacity of one, whereas the tactical improvement simulation has all three processes share the same resource with a capacity of three. Our simulation model for the tactical improvement can be seen in *Figure 4* below. Note that the resource animation only shows a server appearing behind one of the three stations. This is due to the tactical improvement only using a single resource, and Arena cannot represent a single resource in more than one location. This same error can be observed in the strategic improvement.

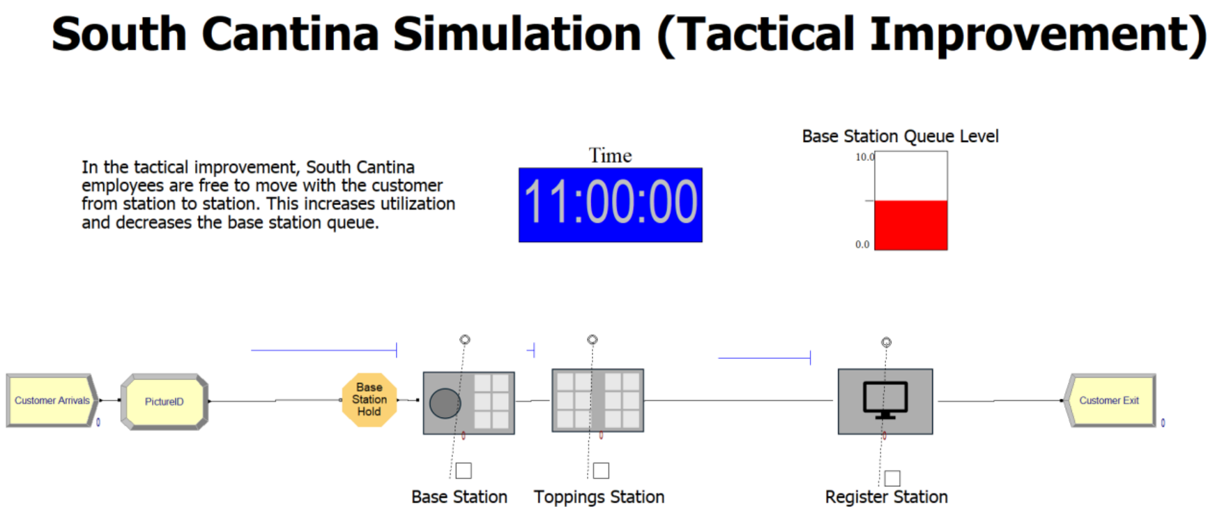

Figure 4: Tactical Improvement Simulation

We chose to model our simulation to have three different processes rather than one singular process that combines the base, toppings and register station. We did this to maintain our FIFO (first in first out) nature of the system. Modeling our simulation as a singular process could potentially result in customers arriving later, finishing the process before customers arriving earlier.

The tactical improvement system's performance relative to the KPI's across 20 replications is summarized in *Table 6*.

Table 6: Tactical Improvement's Queue Length Statistics Relative to KPI Goals

Maximum Base Station Queue Length Statistic	Simulated Value	KPI Goal
Mean	2.85	≤6
Standard Deviation	0.988	N/A
Maximum	5	≤8

The simulation results show a clear impact of the tactical improvement compared to the baseline for our KPI goals. We see a reduction in our maximum average queue length from 6.2 to 2.85 customers and a decrease in our one replication maximum from 10 customers to 5.

Furthermore, we created a confidence interval for the difference of means between the tactical improvement and the baseline to validate the statistical significance of our decrease in mean maximum base station queue length.

$$\hat{\mu}_1 - \hat{\mu}_2 \pm t_{v,\frac{\alpha}{2}} \cdot \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$$

Figure 5: Sample Calculation for 95% CI for Difference of Means

Figure 5 shows a sample calculation for the difference of means. For this calculation, $\hat{u}_1$ and $\hat{u}_2$ correspond to the average maximum queue length of the baseline and tactical improvement respectively. Similarly, S_1 and S_2 correspond to the standard deviation in the maximum queue length of the baseline and tactical improvement. We can see the results of these calculations in *Table 7* below.

Table 7: Tactical Improvement and Baseline Comparison

Decrease in Average Maximum Queue Length	95% Confidence Interval
3.35	[3.04, 3.66]

From these calculations, we see a significant difference in the average maximum queue length between the baseline and tactical improvement, 3.35 specifically. We can also conclude that there is strong statistical evidence that our tactical improvement model is better than the baseline since the confidence interval does not contain zero.

Our next step was to calculate the cost to execute this tactical improvement. As seen in *Table 6*, we assume two primary costs, training material development and training sessions to cross train the employees to work on all 3 stations. We estimate 10 and 15 hours for these tasks respectively at a cost of $20/hour (hourly wage of Union South employees). This comes to a total cost of $500.

Table 8: Cost analysis of the Tactical Improvement

Functionality Update	Task	Estimated Hours	Rate per hour ($)	Cost = Est. Hours * Rate per hour
Employee Training	Training Material Development	10	$20	$200
	Training Sessions	15	$20	$300
Total		**25 Hours**		**$500**

5. Proposed System: Strategic Improvement

For our strategic improvement towards reducing queue length before the first station during peak hours, we plan to introduce a new mobile ordering feature. Mobile orders would be processed by a single employee in a separate, non-customer-faced assembly area. This line will not require a checkout process, as payments can be made via an online ordering interface. This ordering can be integrated into the existing “Wisconsin” app, widely used for campus information. This update will allow students and faculty to place orders directly through the app.

Key Features of the Process:

1) Pre-Order and Schedule Pickup: Users can place their orders in advance, selecting their desired pickup time based on their schedule. This feature is especially beneficial for students with a short lunch break.
2) Real-Time Order Status: After placing an order, users can track the progress and receive updates on the preparation status. They will be notified when their order is ready for pickup, ensuring they can collect their meal without unnecessary waiting.
3) Dynamic Wait Time Information: Before ordering, the app will display an estimated wait time, reflecting current restaurant traffic and order volume, for example 9 orders currently in line. This allows users to make informed decisions about ordering based on their available time.
4) Flexible Payment Options: Payments can be made conveniently via Wiscard or credit/debit card directly through the app, streamlining the transaction process.
5) Notifications and Alerts: Users receive alerts when their order is ready, minimizing wait time, reducing queue length, and improving the overall collection experience.
6) Dedicated Pickup Station: A clearly designated area in South Cantina will be set up as the pickup station. This setup will ensure that the area is easy to locate and exclusively used for picking up orders, thus avoiding confusion and congestion. Orders will be organized into three alphabetical groups based on the customer's first name. This grouping method will simplify the process of locating orders, as customers can go directly to the segment that corresponds to the first letter of their first name.

To set up our simulation model for strategic improvement, we created two different ‘lines’. One line is dedicated to online orders whereas the other is for in-person customers. The online order line follows the same processes and distributions as the in-person line with the key difference of the register station. In the online order process, there is no register station since customers pay for their meals on the online portal. We distribute the three employees staffed across both lines, 2 working on the in-person line and 1 working on the online order line. Both the in-person and online order line implement the tactical improvement as well with employees following customers in a conveyer system rather than being assigned to a station.

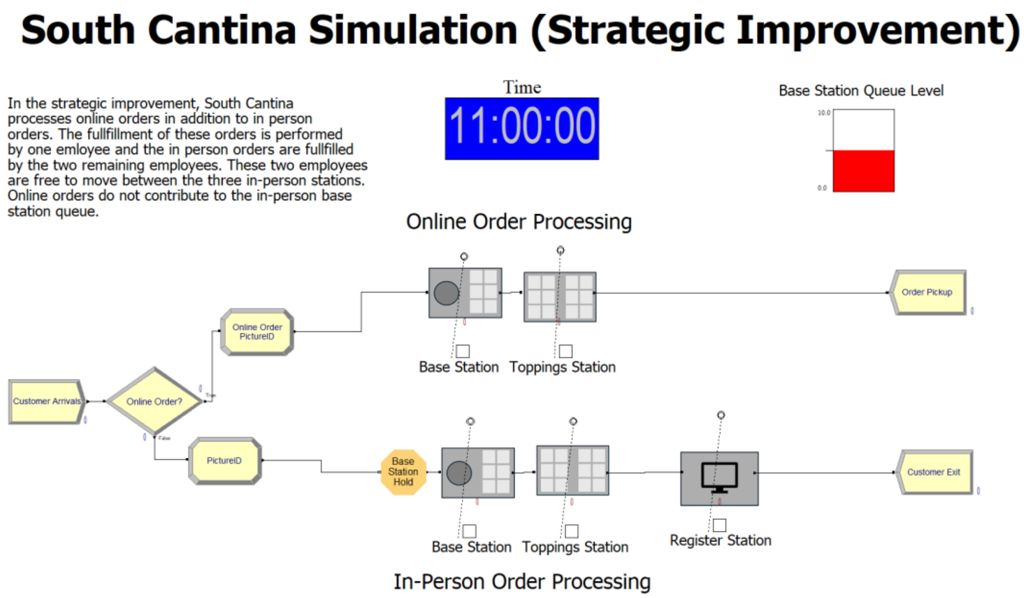

Figure 6: Strategic Improvement Simulation

Table 9: Strategic Improvement's Queue Length Statistics Relative to KPI Goals

Maximum Base Station Queue Length Statistic	Simulated Value	KPI Goal
Mean	3.6	≤6
Standard Deviation	1.23	N/A
Maximum	6	≤8

We created another confidence interval for the difference of means between the strategic improvement and the baseline to validate the statistical significance of our decrease in mean maximum base station queue length. Using the same sample calculation shown in *Figure* 5 while replacing $\hat{u}_2$ and S_2 with the mean and standard deviation of the maximum queue length of the strategic improvement. We can see the results of these calculations in *Table 10* below.

Table 10: Strategic Improvement and Baseline Comparison

Decrease in Average Maximum Queue Length	95% Confidence Interval
2.6	[2.27, 2.92]

Similarly to the tactical improvement, we can see a smaller, yet significant, difference in the average maximum queue length between the baseline and strategic improvement, 2.6 specifically. We can also conclude that there is strong statistical evidence that our tactical improvement model is better than the baseline since the confidence interval does not contain zero.

Table 11: Cost Analysis of the Integration of a Mobile Ordering System

Functionality Update	Task	Estimated Hours	Rate per hour ($)	Cost = Est. Hours * Rate per hour
Design Updates	UI/UX Design Updates	12	$17	$204
	Graphic Design Elements	6	$17	$102
	User Testing	5	$17	$85
Testing	Functional Testing	7	$17	$119
	Integration Testing	3.5	$17	$59.50
Payment Integration	Payment Gateway Configuration	20	$17	$340
	Transaction Testing	10	$17	$170
	Security Checks	15	$17	$255
Communication Updates	Push Notifications System Update	8	$17	$136
	Email Notification Integration	4	$17	$68
	SMS Integration Updates	3	$17	$51
Pick-Up Area Setup	Physical Space Design and Setup	20	$16	$320
	Signage (Materials)	5	-	$100
Employee Training	Training Material Development	10	$20	$200
	Training Sessions	15	$20	$300
Hot Food Table	Install a Hot Food Table	2	-	$1500
Miscellaneous	Project Management	10	$17	$170
	Quality Assurance	5	$17	$85
	Implementation	5	$17	$85
Total		**143.5 Hours**		**$4260.50**

Table 11 describes the costs associated with implementing the strategic improvement. Our primary cost lies in the two hot food tables, at $750 per unit, to be purchased to set up the online order line. The rest of the costs are regarding setting up the online ordering system and employee training for them to learn the skills to work in all the stations.

When building our simulation, we used a decide module to sort between online orders and in-person orders. We initially assumed that 33% of orders would be online orders, we found this value from an external source for Chipotle, a restaurant with a similar configuration. The value was also confirmed by an ex-employee of Chipotle. Online orders ease the in-person strain on the restaurant, thereby achieving our objective of keeping the maximum queue as small as possible. When varying the percentage of online orders to 20% and 40% we found the maximum queue length values for the simulation. These values are shown in *Figure 7*.

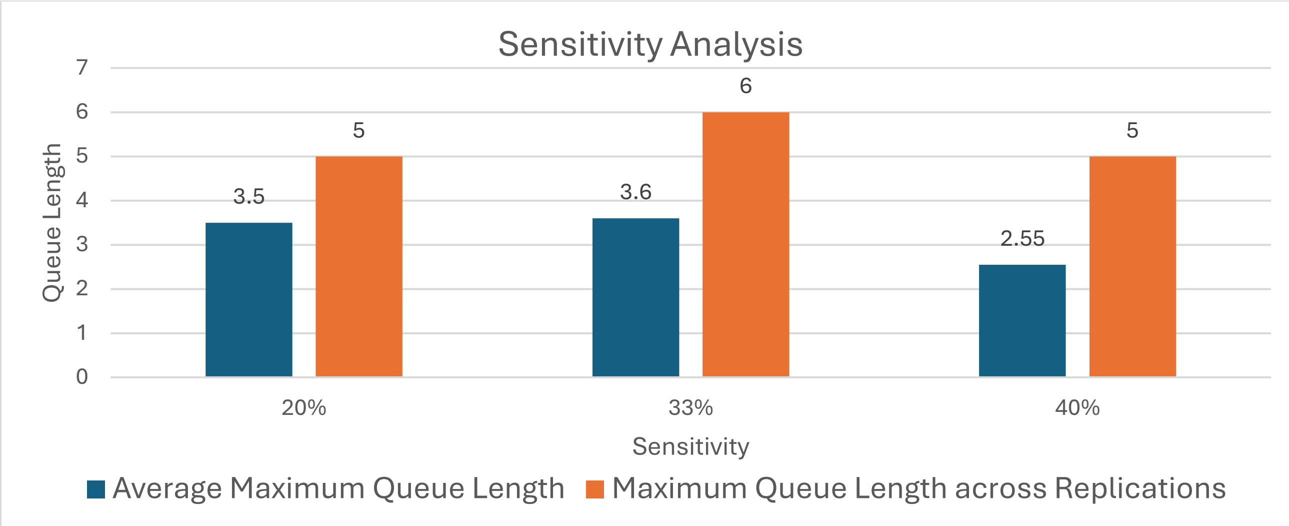

Figure 7: Sensitivity analysis of the Strategic Improvement

We find the maximum queue length across replications is insensitive across lower and higher percentages of online orders. For average maximum queue length is sensitive to the percentage of online orders. The greater the percentage of online orders, the smaller the average maximum queue length across replications. Decision makers should take this sensitivity into consideration when deciding between the tactical and strategic improvements. If online orders are expected to comprise a high percentage of total orders, then the strategic improvement may be superior to the tactical despite the greater average maximum queue length at our predicted conditions of 33% online orders. In this scenario, more resources may need to be devoted to the fulfillment of online orders, as the rate of online orders may overwhelm the single employee allocated to that line in the current model.

6. Recommendation

The analysis of the simulation data strongly suggests adopting the tactical change as the optimal enhancement for South Cantina. This decision is informed by its significant impact on reducing average maximum queue lengths, directly addressing the primary operational challenge of managing peak-hour customer congestion. By implementing this improvement, we are poised to meet and surpass our key performance indicator targets, enhancing the customer experience and minimizing congestion in Union South.

Table 12: Statistical Analysis Summary Table

System Type	Decrease in Maximum Queue Length	95% Confidence Interval
Tactical Improvement and Baseline	3.35	[3.03,3.66]
Strategic Improvement and Baseline	2.60	[2.27,2.92]

The statistical analysis reveals that the baseline system at South Cantina has an average maximum queue length of 6.2, with a confidence interval of 5.40 to 6.99. This queue length is problematic, as it is likely to interfere with foot traffic within Union South and potentially lead to customer dissatisfaction and balking. However, the implementation of the tactical improvement presents a significant reduction, bringing the average maximum queue length down to 2.85, a net decrease of 3.35, with a confidence interval of 3.03 to 3.66. This change indicates a robust and statistically significant improvement in managing congestion in Union South.

In parallel, the strategic improvement, which involves the introduction of a mobile ordering system, also reduces the queue length to an average of 3.6, a net decrease of 2.60, with a confidence interval of 2.27 to 2.92. Although this also represents an improvement over the baseline, the tactical improvement yields a shorter queue length overall.

The recommended tactical improvement, priced at $500, is a cost-effective approach with a primary benefit of enhancing employee utilization. By having customers interact with only one employee throughout the service, it ensures that staff workload is evenly distributed, effectively reducing the queue length. The feasibility of this initiative is high, given its reliance on optimizing current workflows rather than introducing new technologies.

The tactical improvement is proposed at a cost of $500, substantially lower than the $4260.50 estimated for the strategic improvement. This approach is not only cost-effective but also leverages the existing workflow, enhancing employee utilization without the need for substantial new technological investments. By having customers interact with only one employee throughout their service experience, we create an operational flow that evenly distributes the workload among staff members, thus reducing the overall queue length.

The transition to this improved system may present challenges, including staff adjustment to the new method and potential initial customer confusion. These risks are inherent in any change but are considered manageable through targeted training and effective communication strategies. Relative to the strategic improvement, the tactical improvement presents far fewer logistical challenges with its implementation. To build on the benefits of the tactical improvement, complementary strategies such as dynamic staffing could be introduced. This would allow South Cantina to maintain a high level of service during varying customer volumes.

Considering the substantial cost savings of the tactical improvement over the strategic option, along with its considerable operational benefits and minimal implementation risks, this approach is strongly recommended for South Cantina. It is notably effective in reducing the maximum queue length, which aligns with our primary KPI focus. By optimizing the utilization of staff, having customers interact with just one employee throughout the service, the tactical improvement promises to significantly streamline service delivery. This strategy not only enhances customer satisfaction by reducing wait times but also likely increases throughput, thus contributing positively to the restaurant’s overall performance and achieving a more efficient operation that resonates with our goal of improved customer flow during peak hours.

7. References

[1] "Headcounts of Degree Seeking Students," Workbook: Trends in student enrollments, https://viz.wisc.edu/views/TrendsinStudentEnrollments/HeadcountsofDegree-SeekingStudents?%3Aembed=y&%3AisGuestRedirectFromVizportal=y (accessed Apr. 23, 2024).

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